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CLOUD-DRIFT WIND ESTIMATES DURING FGGE

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1. Introduction

During the FGGE year of 1979, five meteorological satellites were positioned in geostationary orbit at intervals of approximately 70 degrees of longitude. Imagery from these satellites was used to produce estimates of wind by tracking identifiable cloud targets through a sequence of images. This generated a set of wind observations covering most of the area equatorward of about 45 degrees of latitude. Figure 1 illustrates the configuration of the geostationary satellite system during 1979. Data from the Japanese Geostationary Meteorological Satellite (GMS), stationed at 140E, were processed by the Japanese Meteorological Satellite Center (JMSC) in real time twice daily and were transmitted via the Global Telecommunications System. The two U.S. satellites (GOES West - 135W and GOES East - 75W) produced data which were likewise processed in real time by the U.S. National Environmental Satellite Service (NESS)[1], but thrice daily, and transmitted on the GTS. METEOSAT, at the Greenwich meridian, was operated by the European Space Agency (ESA) until November 25, 1979. These data were also processed in real time and made available through the GTS.

Imagery from the Indian Ocean Satellite - actually an older GOES which was reactivated and moved to 59E - was processed *post facto* by ESA and by the Space Science Engineering Center of the University of Wisconsin (UW/SSEC). The latter also reprocessed portions of the real time data generated by the three operational centers. Somewhat different techniques were used at the processing centers. Nevertheless, the total result of these activities is a data set of unparalleled magnitude, providing meteorologists with an early global view of the wind field, with special emphasis on the tropics.

The purpose of this note is to review the procedures and techniques used by the data producers to generate the data, which are in wide use in the research community, and to summarize the experience thus far with respect to their quality and utility. The impact of cloud drift winds on forecast models is not addressed. In the next section, the process of transforming image data to wind vectors is discussed first in general terms, followed by a more detailed exposition of the practices at each Center. Emphasis is placed on the differences between the processing techniques used in each system.

An assessment of the quality of the data is given in the third section. This uses as vehicles for assessment, collocation of the cloud-drift winds with other kinds of wind reports; quality control procedures including a special effort conducted in the U.S. to edit the FGGE data through subjective evaluation by skilled synoptic meteorologists, and finally the treatment of the data by analysis systems.

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[1] Now the National Environmental Satellite and Data Information Service (NESDIS)

The fourth section reviews the use of the cloud-drift wind data by global data assimilation systems, including quality control and relative weighting. Problems encountered in using the data are also discussed.

A summary concludes the note.

2. Production of FGGE cloud-drift wind data sets[2]

2.1 General

A set of cloud-drift wind vectors is produced as a result of five activities:

- Registration - cloud images from the satellites must be adjusted so that the relationship of a cloud target to earth locations is known to considerable accuracy. This enables the displacements beteeen successive images to be calculated accurately. The U.S. procedure is to compute approximate registration from the orbital and scan parameters of the spacecraft, and then adjust these by matching a set of known landmarks; e.g., White Sands, New Mexico.

- Selection - To be a suitable target, a cloud must persist in recognizable form through at least two, and preferably three, sequential images. It must also be advected <u>by the wind</u>, as opposed to moving with a wave or appearing to move as a result of development. Typically, suitable targets tend to be found at two levels: in the lower troposphere where cumulus cloud tend to move with the wind near cloudbase; and in the upper troposphere where cirrus elements may be tracked. Relatively few targets can be selected in the middle troposphere.

- Tracking - The displacement of the selected target is calculated over the sequence of images. A wind vector is then determined from the displacement divided by the time interval between images.

- Altitude Assignments - The wind vector is then assigned to an altitude most representative of the observed motion.

- Quality Control - Because all of the above steps are vulnerable to errors of various types, it is necessary to remove unrepresentative vectors, or at least identify them, before transmitting them to users.

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[2]Most of the material in this section h as been liberally extracted from Hubert (1979); Kodaira et. al. (1981); and Mosher (1979).

Two general approaches to selection and tracking have been used. The first is automatic and relies on pattern correlation techniques for matching cloud patterns between successive images. The second is essentially manual: an analyst is presented with an animated (either photographically [movie loop] or electronically) sequence of images and selects suitable targets based on knowledge of atmospheric motions and experience. These are used in varying degrees of mixture at the several Centers.

Altitude assignment techniques can also be described in two broad categories. One relies on climatology: the wind vectors are assigned to the height most commonly associated with the type of cloud target. The other makes use of the cloud brightness temperature, matching it with the latest estimate of the temperature in the area. The altitude at which the best match occurs is assumed to be the altitude of the cloud. As in selection and tracing, these two are used in varying degrees at the processing Centers.

Quality control techniques used for editing cloud vectors generally use a mixture of automatic and manual procedures. Typically, a vector will be compared with some a priori estimate of the wind at that location (from a forecast or the most recent analysis), with neighboring cloud-drift winds, or with neighboring winds from other sources. Vectors identified as suspicous are referred to an analyst for final judgement.

Data sets produced by these procedures have certain unique characteristics. The vectors (especially those produced by the U.S.) generally tend to be at two levels - low and high - corresponding to the two basic types of targets, cumulus and cirrus clouds. Low level and high level winds tend not to overlap. If low-level targets are visible, it is because there are no high-level targets to obscure them. Areas of thin cirrus occasionally allow tracking of both low- and high-level targets, but this accounts for no more than 10% of the total area. Most of the high-level targets come from thicker cirrus, which obscures lower targets. Middle clouds are most often found underneath cirrus shields and are frequently amorphous and difficult to track, consequently, few vectors are obtained in the middle troposphere. The tracking procedures used by ESA and JMSC during FGGE generated more middle cloud vectors and more overlap between high and low vectors than were generated by NESS.

Coverage afforded by cloud-drift vectors is generally confined to the area equatorward of 45° latitude, although large displacements can be measured with acceptable accuracy as much as 50° from the satellite subpoint. There is some deterioration of accuracy with distance away from the subpoint, but it is not serious except near the extreme limits.

The principal sources of observational errors in cloud-drift vectors are the selection of suitable targets and the assignment of the vectors to the proper altitude. Of these, the latter is probably the most serious.

The next paragraphs summarize the details of cloud-drift vector processing at the several centers during the FGGE year.

2.2 United States (NESS)

Low-level winds from the two U.S. satellites were generated operationally during 1979 using an automatic pattern recognition technique. It continues in use today. Areas covering 125km x 125km with less than 70% coverage by high or middle clouds are examined for suitable low cloud clusters. The areas are positioned on a staggered grid - at the corners and centers of 5° latitude squares. Tracking is accomplished at each grid point by searching a prescribed section of successive images and correlating all pairs of coincident picture elements at each successive lag location. The location of maximum correlation indicates the displacment of the cloud cluster between the two images. Vectors thus determined are assigned to the points of staggered grid. Climatological altitude assignment is used; all U.S. NESS low level vectors are assigned to 900mb. A quality indicator or confidence factor is assigned to each vector depending on the level of agreement with its neighbors and upon the degree of peakedness of the correlation field: strongly peaked correlations suggest relatively high confidence. Quality control is performed by comparing each wind to an analysis of the combined 850 mb first guess and derived winds. Deviations which are too large or which unduly disturb the vorticity field, cause the offending vector to be removed.

NESS high level winds were produced manually during FGGE using movie-loop techniques. These have changed since 1979 in some rather significant ways, but this paragraph summarizes only the practices used during the FGGE year. A sequence of images was projected on an electronic digitizing board. The operator, examining both motion and brightness temperatures, selected targets and measured their displacements by marking their initial position (latitude and longitude) and final position on the digitizing board. These positions were automatically entered onto computer cards so that displacements could be calculated. Altitude assignment was done by matching the brightness temperature of the cloud target with the temperature profile of the latest analysis. Because the selection and tracking process required the analyst to use judgement, quality control procedures at this point consisted of simply displaying the calculated vectors for gross errors.

2.3 Japan (Meteorological Satellite Center)

Japanese low-level winds were obtained during FGGE using a mixture of manual and automatic methods. Images were presented to an operator on a video display device. The operator selected the targets to be tracked. A search was then made of the next image (0.5h interval) using cross-correlation calculations to locate the terget. This was done first with a coarse resolution image to obtain a first estimate of the displacement. Then, it was repeated with a higher resolution image to obtain a final value. Three successive images were used, but the final vector came only from the last two. Because the operator selected targets of opportunity, no grid array was used. Altitude assignment used matching between the cloud-top temperature and a recent analysis or forecast. Later studies showed that low-level clouds move with the wind near their base rather than their top, so this was a source of error.

High level winds were obtained using a movie-loop technique similar to that described in the previous section. The altitude assignment differed from the U.S. practice, however, in that high-level vectors were assigned to the climatological tropopause. This proved to be a serious deficiency, as will be illustrated later in this note, and was subsequently changed in December 1982.

Quality control for all winds used a combination of objective and subjective methods. For each vector, the correlations between successive images, the variations of cloud temperature from picture to picture, and the calculated accelerations were required to be within pre-specified limits. Failure resulted in deletion from the data set. The surviving vectors were displayed on a video device for the operator's judgement, and where possible, were compared with nearby radiosonde winds. Synoptic reasonableness and consistency were principal criteria for retention.

2.4. Europe (European Space Agency)

Cloud-drift wind vectors from METEOSAT-1 imagery produced by ESA at Darmstadt, F.R.G. Operations during the FGGE year were somewhat limited, being terminated by satellite failure on November 25, 1979. METEOSAT-2 winds again became available in May 1982 once per day (noon, Greenwich), and twice per day in September 1982. The wind determination technique used by ESA during FGGE depended on pattern recognition at all levels and was highly automated. Correlation among three successive images was done in two steps, first using IR then visible imagery. In the IR search a segment of 32x32 elements from the middle image searches for the best correlation position with a 96x96 array in both the first and last pictures. With this estimate the vector is fine tuned using only the first and last images - 56x56 array from one searcher within a 64x64 array of the other. Altitude assignment was done by matching the brightness temperature of the target cloud with the closest temperature profile obtained from a recent analysis or forecast. Quality control was performed principally by subjective methods by a meteorologist with the aid of computer-interactive graphics displays.

2.5. United States (Univ. of Wisconsin/SSEC)

The University of Wisconsin/SSEC cloud-drift wind processing system for FGGE was both manual and automatic. It relied on skilled analysts and computer interactive graphics, as in the ESA quality control system, but allowed the analyst a much larger role, as in the Japanese and U.S./NESS systems. Mosher (1979) notes that target selection is best done by people, for judgement is required, while tracking and other activities involving calculation is best done by computer.

The UW/SSEC system displayed image data on a video device. The operator selected the target, and the computer tracked it via correlation techniques, calculated the wind vector, and displayed it for the analyst's approval. This system was used for all targets, regardless of type or levels cloud heights were assigned by the cloud temperature/nearby profile matching technique. A correction was applied to allow for the fact that clouds sometimes appear warmer than they actually are, because clouds are not black-body radiators. The correction makes use of visible data, and so is not available at night.

Three images separated by 0.5h were used to generate vectors. Each target thus produced two vectors, which were used in quality control. Pairs differing by more than 5 m/s in either component were rejected. Surviving pairs were averaged to produce the final vector. A neighbor check was also used.

3. Assessment of Cloud-Drift Wind Data Quality

Any set of observations of the atmosphere is beset with errors. In the absence of an absolute standard of truth, assessing the quality of a particular set consists of applying a number of different tests, none of which are entirely satisfactory. Judgement thus rests on the sum of fragmentary and occasionally contradictory evidence and is rarely either conclusive or absolute.

This section presents three such fragments. First, comparisons between approximately coincident cloud-drift vectors and other winds are discussed. Second, results of quality control procedures illustrate the number of "rogue" observations present in a data set. Finally, the relative compatibility with data assimilation systems of several kinds of wind data is considered.

3.1. Collocations

Collocation comparisons consist in matching a cloud-drift wind vector with a nearby vector from some other source, where "nearby" is defined as a pre-specified window in three-dimensional space and time. Obviously, the atmosphere has some variability over such a window. This acts to inflate the difference between the wind vectors to some extent.

This discussion will consider two categories of collocations: Type 1, where cloud-drift wind vectors from two adjacent satellites are collocated in the area of overlap; and Type 2, where cloud-drift wind vectors are matched with rawinsondes and aircraft. The former are a measure of the uncertainty in cloud-drift vectors. The latter contain errors both of the cloud-drift wind and the other observation, as well as the natural variability across the collocation window.

Two sources of information are used here: a collocation program carried out by the U.S. (NESS) under the auspices of a working group called Coordination for Geostationary Meteorological Satellites (CGMS) and an independent program conducted by the U.S. National Meteorological Center. The NESS program uses an elliptical space window oriented along the direction of the wind, and ± 3h in time. Type 1 vectors are considered collocated in the vertical if they are in the same category: low (surface - 700 mb), mid-level (699 - 400 mb), or high (<400 mb). Type 2 vectors are matched if the vertical window is 500 m or less. A description of the NESS collocation program may be found in Whitney (1983) and several working papers for the CGMS made available through personal communication with L. F. Whitney.

The NMC program matches reports within three degrees of latitude and one hour. No Type 1 collocations are done; however, Type 2 matches included both rawinsonde and aircraft, separately.

Table 1 presents comparisons between adjacent satellites in the areas of overlap for the period 5-10-79 through 6-5-79, during the second Special Observing Period, taken from the NESS collocation program. The numbers are quite uniform, with only the METEOSAT-GOES/E high level comparison exhibiting less agreement.

Table 1. Root-mean-square vector differences (m/s) between collocated cloud-drift wind vectors produced by two adjacent satellites, for the period 5-10-79 thru 6-5-79.

Satellites	Low (sfc - 700 mb)	High (<400 mb)
METEOSAT - GOES/E	4.5	12.0
GOES/E - GOES/W	4.1	8.0
GMS - GOES/W	5.6	9.4
GOES/E/W - UW/SSEC	4.4	8.5
METEOSAT - UW/SSEC (Indian Ocean)	4.9	8.3

Note especially that the GOES/E - GOES/W comparison, where winds are produced using identical equipment, procedures, and personnel, are the lowest of all, but not by much. This suggests that the uncertainty in cloud-drift winds is not due to differences in techniques used at the various processing centers.

Table 2 gives the Type 2 NESS comparison against rawinsondes for the same period, only for the operational vectors. Indian Ocean vectors, or GOES vectors reprocessed by UW/SSEC, are not included.

Table 2. Root-mean-square differences (m/s) between cloud-drift vectors and collocated rawinsonde vectors, for the period 5-10-79 thru 6-5-79.

Satellite	Low	Mid	High
GOES/E-W	5.6	8.7	13.0
GMS	6.0	9.4	15.8
METEOSAT	6.0	9.1	12.9

The numbers are generally larger for the Type 2 comparisons, but agree well among themselves, except for the GMS high-level winds. This is a consequence of the JMSC climatological altitude assignment referred to earlier. Operational data assimilation systems typically assume rawinsonde RMS vector errors ranging from 3 to 8 m/s (e.g., Bengtsson, et. al, 1982, Table 1). Assuming that cloud wind errors and radiosonde wind errors are uncorrelated, and thus their contributions add as squares, the numbers in Table 2 can be adjusted to range from about 5 m/s to 14 m/s.

Figures 2 and 3 illustrate the comparison of the NESS collocation statistics during the FGGE year with those of subsequent years. Type 1 comparisons are shown in Figure 2. Significant changes have occurred since 1979 mostly in the high-level winds: GOES/W - GOES/E differences have steadily declined, presumably as a result of experience and standardization of practices at NESDIS. GOES/W - GMS differences declined remarkably in the summer of 1981.

These figures show considerable variation with time in the high-level winds. Users of this database should consider incorporating this fact in their data assimilation systems.

Figures 4 and 5, from the NMC collocation program, display the variations with time in Type 2 collocations for all of the operational geostationary satellites (high level only), for the period October 1978 through May 1980. Collocations of ASDAR (Aircraft to Satellite Data Relay) and radiosonde winds are included for comparison. The RMS vector error is shown in Figure 4; part (a) compares GOES/W and GMS with the ASDAR collocation, and part (b) compares GOES/E and METEOSAT with the ASDAR collocation.

Clearly, the GMS-radiosonde collocations are much larger than any of the others, especially in the Northern Hemisphere winter. The ASDAR-radiosonde trace is relatively constant with time, and generally below 12 m/s: the average over 1979 is 11.7 m/s. Both GMS and GOES/W show large seasonal variations, especially in the former. There is considerable month-to-month variation in the GOES/E-radiosonde collocation, with particularly large maxima in August and December. METEOSAT also shows temporal variations, but with much smaller magnitude.

Averaged over 1979 (through October for METEOSAT), the various systems yield errors of 16.8 m/s for GMS, 14.1 m/s for GOES/E, 13.4 m/s for GOES/W, and 13.5 m/s for METEOSAT. These numbers are slightly higher than the NESDIS collocations in Table 2, but the relative scores agree well.

Monthly-averaged mean speed difference for this period are given in Figure 5. Very large temporal variations are apparent, especially for GMS winds. GOES/W winds were faster than their matched radiosonde counterparts during all of 1979. GOES/E winds began the year with a positive mean difference. METEOSAT mean speed differences were negative throughout the year.

3.2. Analysis of Quality Control Results

The U.S. mounted a "Special Effort" to examine the FGGE data base and edit at least parts of it to ensure a high quality data set. This effort has been discussed by Greaves, et.al., (1979). It involved subjective evaluation of certain data sets, especially satellite derived soundings and cloud-drift winds, by skilled analysts using computer interactive graphics and all other available information. Suspect observations were flagged.

Partial results were presented by DiMego, et.al., (1981). Table 3 has been extracted from that source. Of the vectors edited, about 4% of NESS - produced winds were judged incorrect, while slightly over 20% of the JMSC vectors were so judged. This probably reflects the altitude assignment problems referred to earlier. The remaining producers fall in between. Overall, about 13% of the vectors edited were flagged as incorrect.

These results suggest that the likelihood of encountering "rogue" reports is uncomfortably large in some of the cloud drift wind data sets.

Table 3. Summary of cloud-drift wind vector editing by the U.S. 'Special Effort' team, for the period 1-5-79 thru 1-30-79.

Producer	Total Vectors	Vectors Edited	Vectors Flagged
NESS(GOES/E-W)	34239	7267	292 (4%)
UW/SSEC (GOES/E-W)	76345	6837	803 (12%)
UW/SSEC (GMS, IO)	60526	5927	1161 (19%)
ESA (METEOSAT)	19855	4487	679 (15%)
JMSC (GMS-1)	16093	5700	1127 (20%)
TOTAL	207058	30218	4062 (13%)

3.3. Compatibility with Data Assimilation Systems

This tends to be confirmed by the experience of users who ingest the cloud-drift wind data into data assimilation systems. Although all such systems incorporate automated quality control procedures which screen much of the incorrect data, some inevitably survive to affect the assimilation. A larger precentage of "rogue" reports will contribute to a looser "fit" of that data set by the assimilation system. Other factors may also contribute.

Figure 6, taken from a paper by Halem, et.al (1982), depicts RMS differences between analyses produced by the GLAS[1] global data assimilation system and selected FGGE data sets. In Figure 6a, the fit of the GLAS analysis to four different types of wind information is presented. The range among them is about 2-3 m/s at low levels and 3-6 m/s above 400 mb. A much greater range appears in Figure 6b, comparing the fit of the GLAS analysis to three sets of cloud-drift winds. The analysis thus experiences greater difficulty in fitting the METEOSAT and GMS winds than the NESS winds or any of the other sources. This is consistent with Table 3, where METEOSAT and GMS winds were identified as incorrect much more frequently than the NESS winds.

4. Comments on the Utility of Cloud-Drift Wind Vectors

The preceding assessment of the quality of the cloud-drift winds is reflected in the way data assimilation systems treat the vectors relative to other sources of wind information. Table 4, extracted from Bengtsson et.al. (1982), gives the estimated RMS observational errors assigned to various types of wind observations in the ECMWF assimilation system. The numbers in the table are for each component of the wind, rather than an RMS vector error estimate. Overall, rawinsonde and aircraft are considered the most accurate wind reports, followed by NESS/SSEC cloud-drift winds and then ESA and JMSC winds.

[1]Goddard Laboratory for Atmospheric Sciences

In spite of these relatively large error estimates and the problems of coverage and quality control that have been mentioned previously, cloud drift wind data are regarded by users as very important, especially over vast areas otherwise devoid of wind reports.

Table 4. Estimated observational errors assigned to different wind observing systems in the ECMWF data assimilation system in m/s. Component rather than vector error is presented.

Pressure	Observing System			
	Radiosonde/Aircraft	NESS/UWSSEC	ESA	JMSC
300 mb and above	6	8	8	13
400	5	7	8	10
500	4	7	8	10
700	3	5	8	6
850	2	4	7	6
1000	2	4	7	6

The principal problem encountered is that of quality control. Vectors which have improper altitude assignment and still elude data checks cause considerable difficulties in data assimilation systems. As Bengtsson, et. al. (1982) noted, "... fleets of cloud drift winds are sometimes assigned to completely erroneous heights." In such circumstances, the winds may confuse automated quality control, which is based on spatial consistency between neighboring reports. Several nearby erroneous winds will support each other and may be admitted into the analysis. When this occurs, havoc may result. Hollingsworth, et.al. (1984) present an example of analysis error resulting from suspect cloud drift winds over the Mediterranean.

5. Summary

Cloud drift winds constitute an important component of the FGGE data base. They were generated by four different centers, using somewhat different procedures. Some of those differences had major impact on the quality and utility of the data. The most prominent example is the JMSC procedure for altitude assignment.

There are limitations of the data that users should be aware of. Coverage is limited to equatorward of 45° latitude and tends to be at a single level: high or low, depending on whether the target clouds are cirrus or cumulus. Sources of error include non-advective cloud motions and assignment of the vectors to an altitude unrepresentative of the motion. The latter is by far the most serious.

UW/SSEC and NESS high level winds were produced by systems which allow human judgement a role in target selection. Their data sets have been found to be the the most accurate and reliable. Winds produced by ESA are less highly regarded, perhaps because their more automated system allowed a larger number of incorrect vectors from poor target selections. The JMSC high-level winds during FGGE are subject to serious errors because of the practice of assigning them to the height of the climatological tropopause.

Data users are still learning how to use these data in combination with other types of information. The major obstacle is the automatic removal of groups of erroneous cloud drift winds.

Acknowledgements

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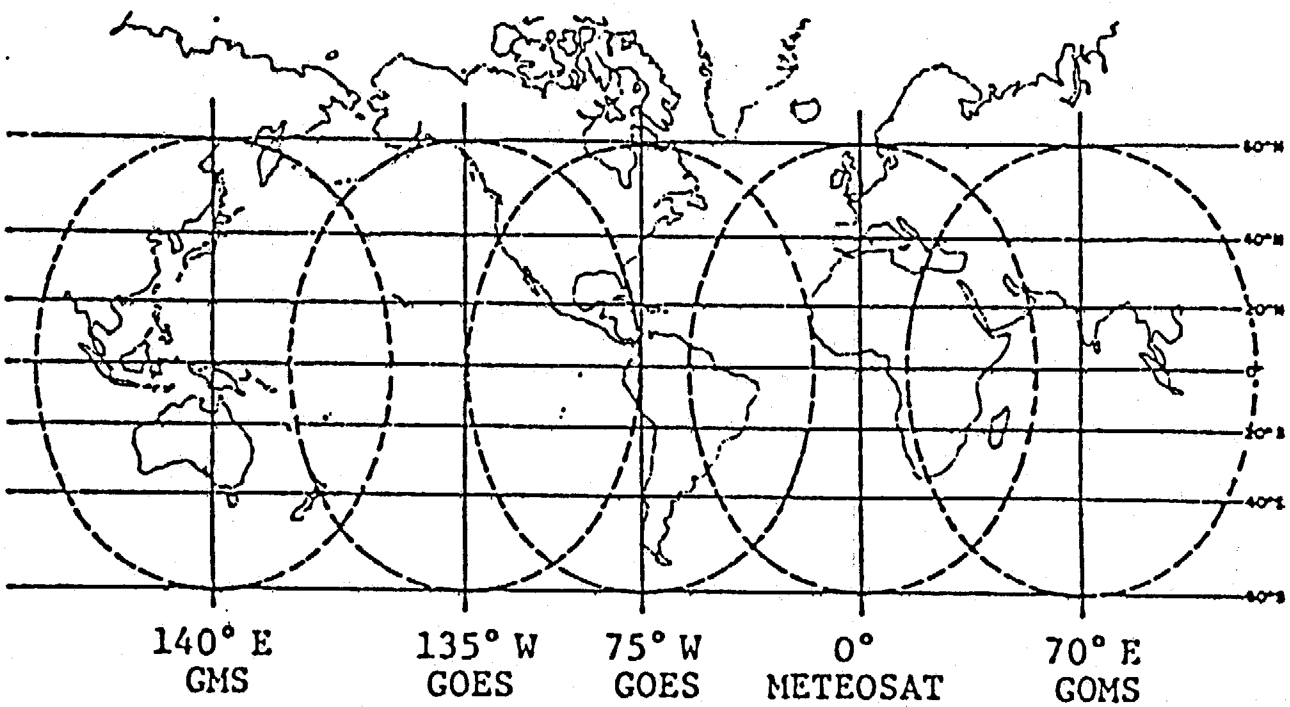

Figure 1. Fields of view of five geostationary satellites in which winds can be derived. During 1979 a backup GOES was operated at 59°E in place of GOMS as shown at 70°E. Outlined areas represent a 60° geocentric angle about each satellite subpoint. After Hubert (1979).

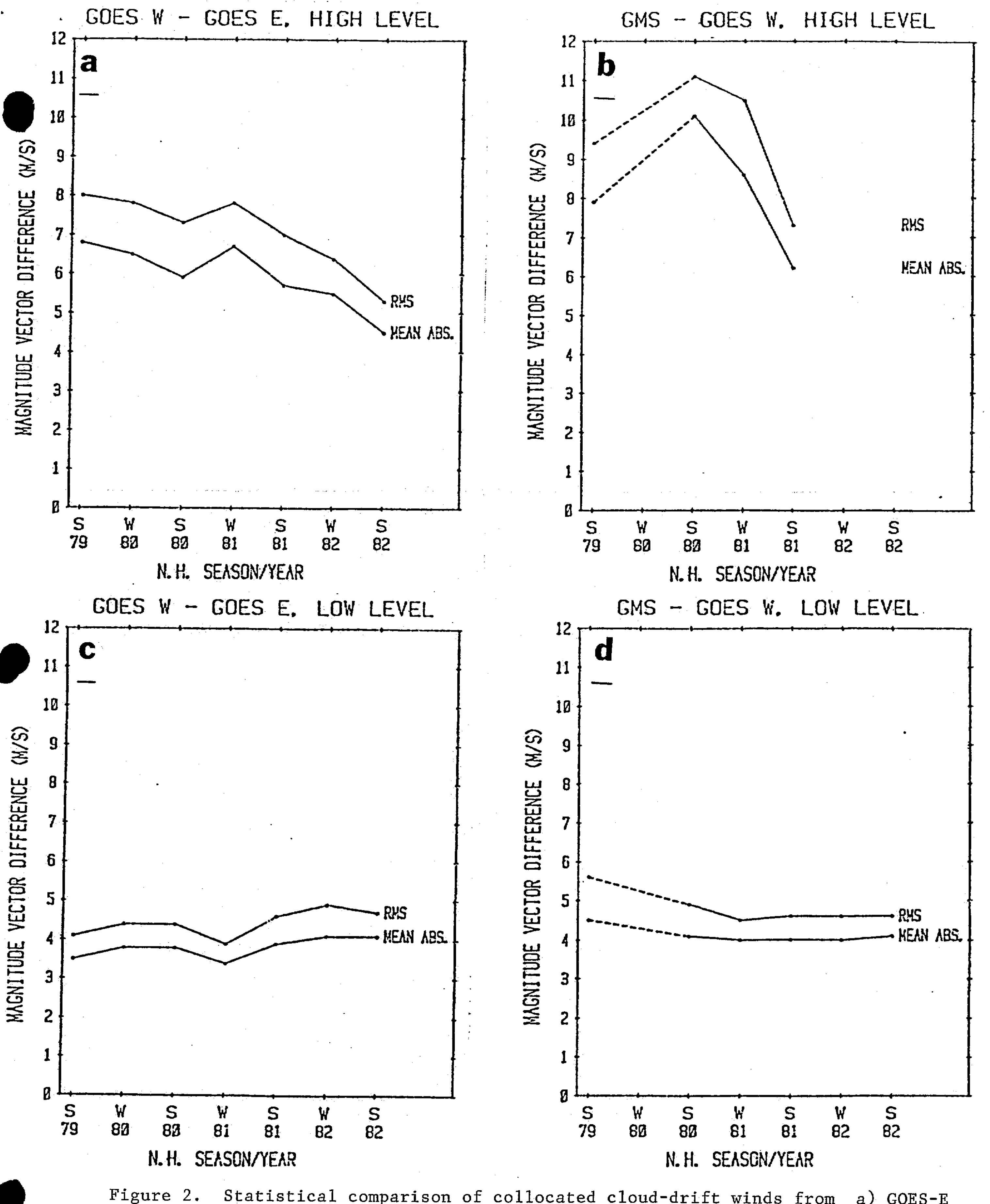

Figure 2. Statistical comparison of collocated cloud-drift winds from a) GOES-E and GOES-W above 400 mb; b) GMS and GOES-W above 400 mb; c) GOES and GOES-W below 700 mb; d) GMS and GOES-W below 700 mb. Taken from CGMS-VII Working Paper, Agenda Item G.1, 4/25/83. Courtesy of L. Whitney, NESDIS.

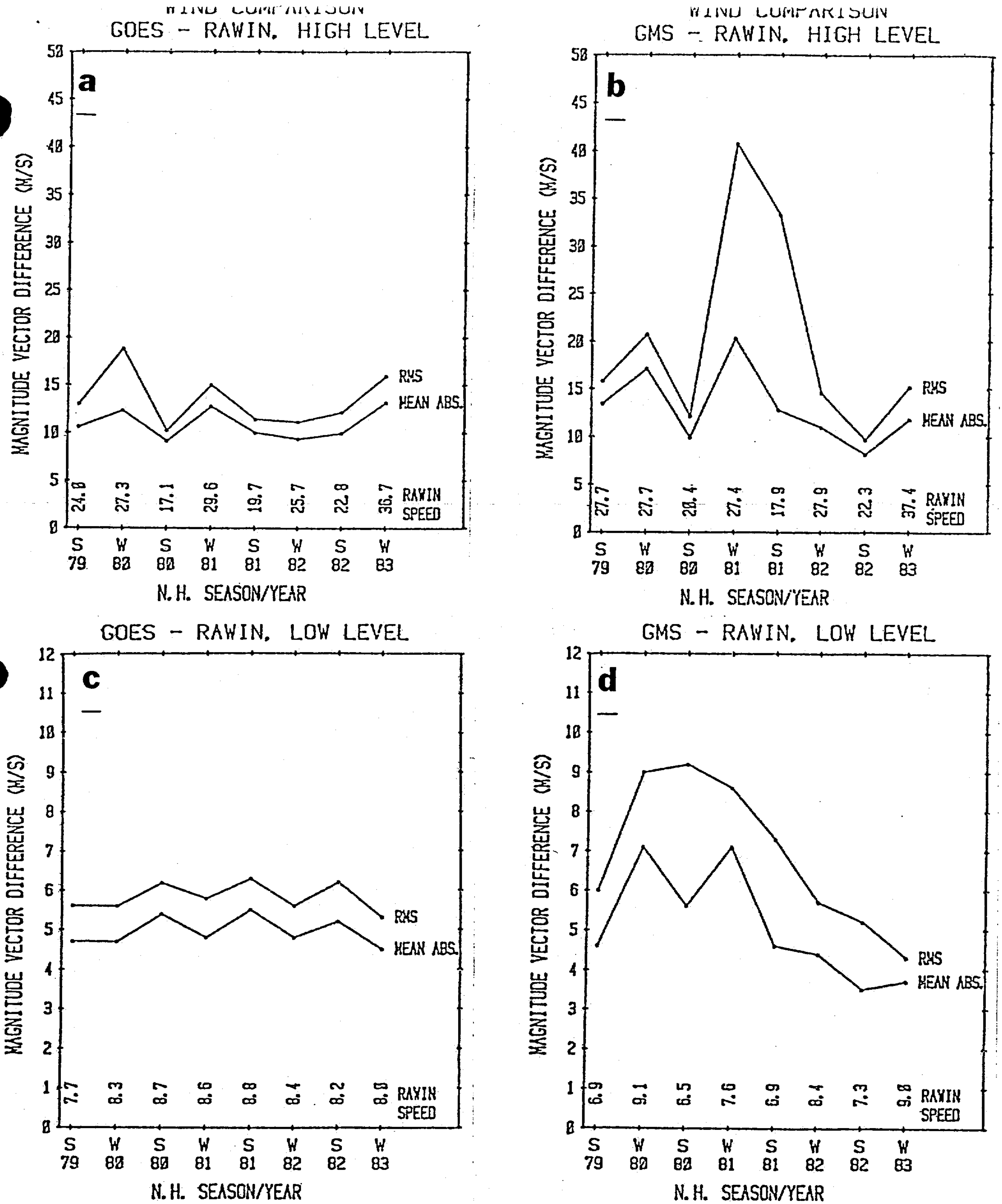

Figure 3. Statistical comparison of collocated cloud-drift winds and rawinsondes: a) GOES above 400 mb; b) GMS above 400 mb; c) GOES below 700 mb; d) GMS below 700 mb. Taken from CGMS-VII Working Paper, Agenda Item G1, 4/25/83. Courtesy of L. Whitney, NESDIS.

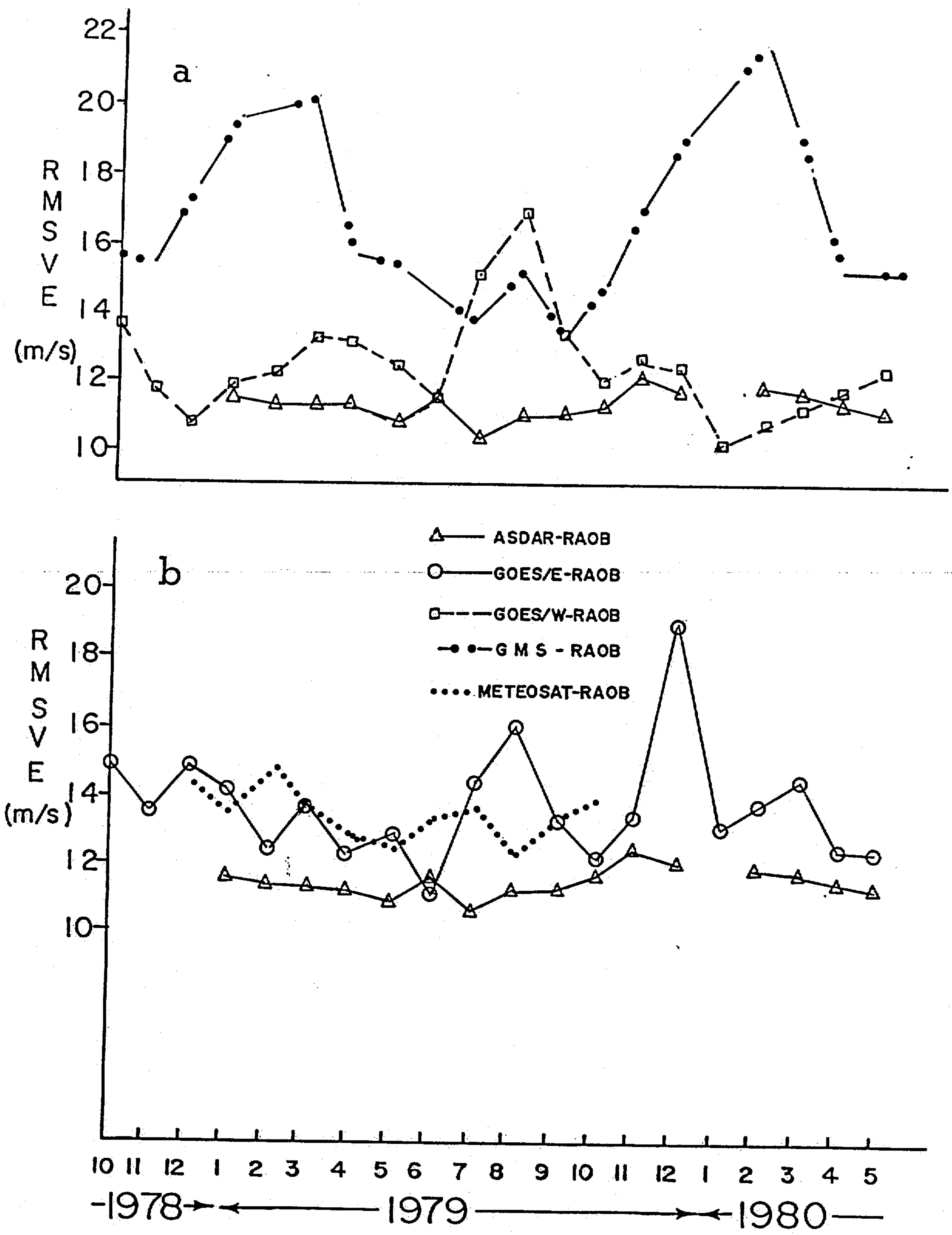

Figure 4. RMS vector differences between wind sensing systems and nearby radiosondes during FGGE, using the NMC collocation program. Collocation window is three degrees latitude and one hour. Part (a) includes GOES-W and GMS comparisons, while part (b) shows GOES-E and METEOSAT. ASDAR vs. radiosonde is included in both.

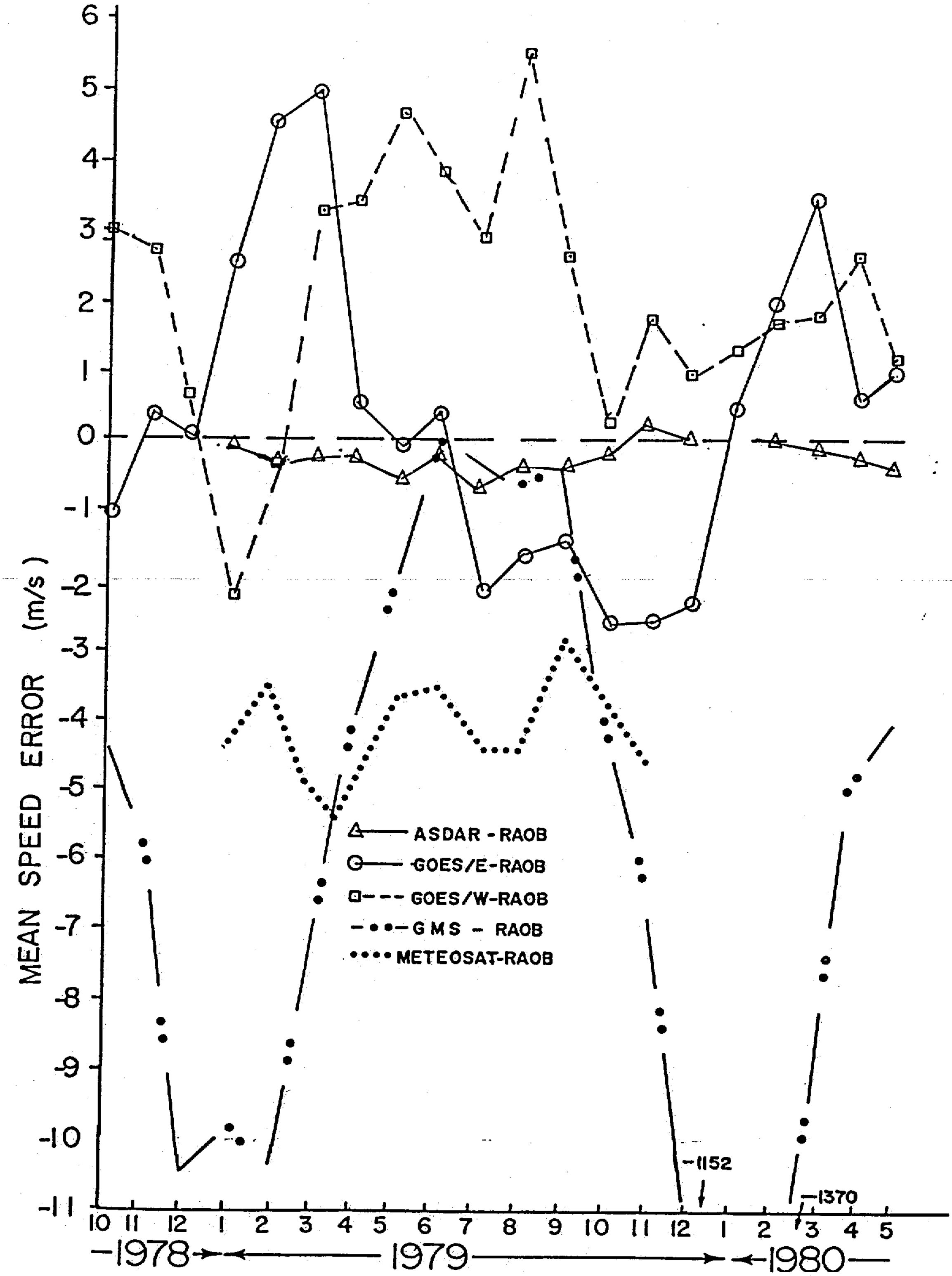

Figure 5. Mean speed differences between various wind sensing systems during FGGE, using the NMC collocation program.

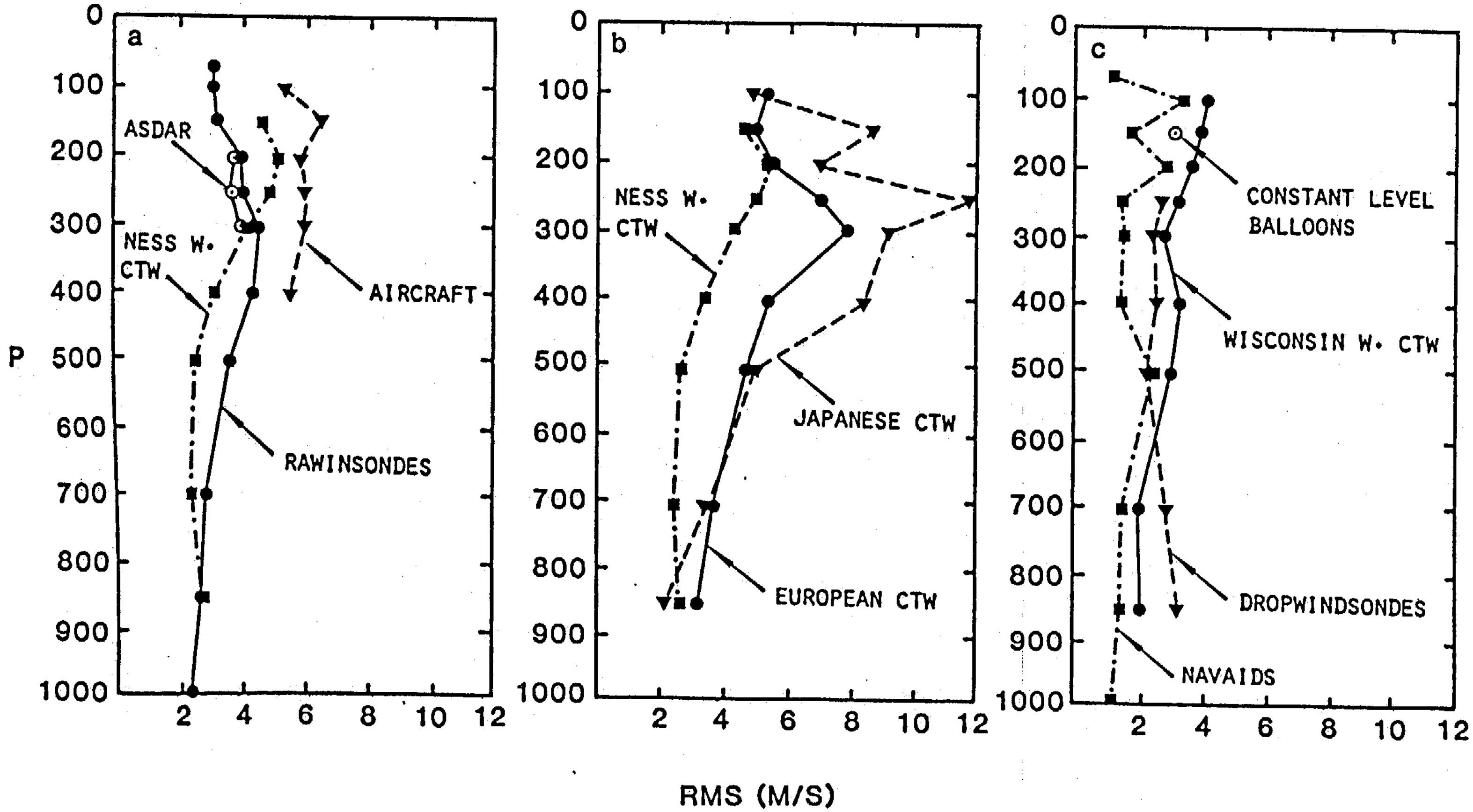

Figure 6. Vertical profiile of rms differences bewteen the FGGE wind analysis and data from different wind observing systems in meters per second. CTW is an acronym for cloud-track winds. a) NESS West cloud-track winds compared with three other wind observing systems. b) Three different cloud-track wind systems compared. c) RMS differences for tropical wind observing systems. After Halem, et al. (1982).